Chemical Engineering Journal 470 (2023) 144169

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Sustainable recovery of high-valued resources from spent lithium-ion batteries: A review of the membrane-integrated hybrid approach

Ramesh Kumar [a], Sankha Chakrabortty [b], Prasenjit Chakrabortty [c], Jayato Nayak [d], Chengjia Liu [a], Moonis Ali Khan [e], Geon-Soo Ha [f], Kwang Ho Kim [f], Moon Son [g], Hyun-Seog Roh [h], Suraj K. Tripathy [b], Byong-Hun Jeon [a,*]

[a] *Department of Earth Resources & Environmental Engineering, Hanyang University, 222-Wangsimni-ro, Seongdong-gu, Seoul 04763, Republic of Korea*
[b] *School of Chemical Technology, Kalinga Institute of Industrial Technology, Bhubaneswar 751024, Odisha, India*
[c] *Department of Chemistry, The University of Burdwan, West Bengal 713104, India*
[d] *Center for Life Sciences, Mahindra University, Hyderabad, Telangana 500043, India*
[e] *Chemistry Department, College of Science, King Saud University, Riyadh 11451, Saudi Arabia*
[f] *Clean Energy Research Center, Korea Institute of Science and Technology, Seoul 02792, Republic of Korea*
[g] *Center for Water Cycle Research, Korea Institute of Science and Technology, Seoul 02792, Republic of Korea*
[h] *Department of Environmental and Energy Engineering, Yonsei University, 1 Yonseidae-gil, Wonju-si 26493, Republic of Korea*

A R T I C L E I N F O

Keywords:
Spent LiBs
Resource recovery
Membrane-based technology
Sustainable approach, Circular economy

A B S T R A C T

Lithium-ion batteries (LiBs) can play a vital role in the stable transition towards a renewable and low-carbon society by replacing fossil fuel-based power sources in transportation, electronics, and energy storage devices. In future, a surge in electric vehicle adoption is expected, which will result in a high demand for LiBs, accumulation of spent LiBs, and challenges in supplying critical metals for battery industries. The sustainable management of abandoned LiBs can be achieved via urban mining to protect the environment from LiB disposal and conventional mining. Currently, <5% of decommissioned LiBs are recycled into valuable resources. Therefore, a paradigm shift in recycling processes is required to change the current recycling status at ground level. Hydrometallurgical processes are most commonly used to leach precious metals (Li, Co, and Ni) from solid to aqueous phases. However, the complete recovery from a leached solution is challenging. This membrane-integrated hybrid approach can facilitate the development of an efficient, eco-friendly, and cost-effective method for the downstream separation and recovery of valuable metals from spent LiBs. This review presents a comprehensive literature survey on the recycling of valuable metals from spent LiBs and further directs research on new membrane-based sustainable approaches to enhance value recovery. A tailor-made membrane in an appropriate module, can be easily integrated with conventional processes to achieve a high degree of process intensification during recovery and boost the scale-up confidence and circular economy approach.

1. Introduction

Lithium-ion batteries (LiBs) are expected to become essential for a cleaner and more sustainable planet, as they may curtail our dependency on conventional fossil fuel-based energy generation with renewable energy sources, for example, solar and wind power [1]. LiBs constitute

Abbreviations: AEM, anion exchange membranes; BMED, bipolar membrane electrodialysis; CEM, cation exchange membranes; CRR, carbothermic reductive roasting; DCMD, direct contact membrane distillation; DESs, deep eutectic solvents; ECR, electrochemical reactor; ED, electrodialysis; EOL, end-of-life; ESM, energy storage material; EV, electric vehicle; FO, forward osmosis; GHGs, greenhouse gases; HGMS, high-gradient magnetic separator; HIMS, high-intensity magnetic separation; IEM, ion-exchange membrane; ILs, ionic liquids; IRMS, induced roll magnetic separator; ISM, ion-sieve membrane; LCO, Li-Co oxide; LFP, Li-Fe-phosphate; LiB, lithium-ion batteries; LISMs, Li-ion sieves membranes; LMO, Li-Mn oxide; MD, membrane distillation; MF, microfiltration; MDCr, membrane distillation crystallization; NCA, Li-Ni-Co-Al oxide; NF, nanofiltration; NMC, Li-Ni-Mn-Co oxide; PIM, polymer inclusion membrane; PIMED, polymer inclusion membrane electrodialysis; PVDF, polyvinylidene fluoride; REEs, rare earth elements; RO, reverse osmosis; SED, selective-electrodialysis; SC-CO_2, supercritical carbon dioxide; SCW, subcritical water; SLM, supported liquid membrane; UF, ultrafiltration; VMD, vacuum membrane distillation.

* Corresponding author.
E-mail address: bhjeon@hanyang.ac.kr (B.-H. Jeon).

https://doi.org/10.1016/j.cej.2023.144169

Available online 19 June 2023